

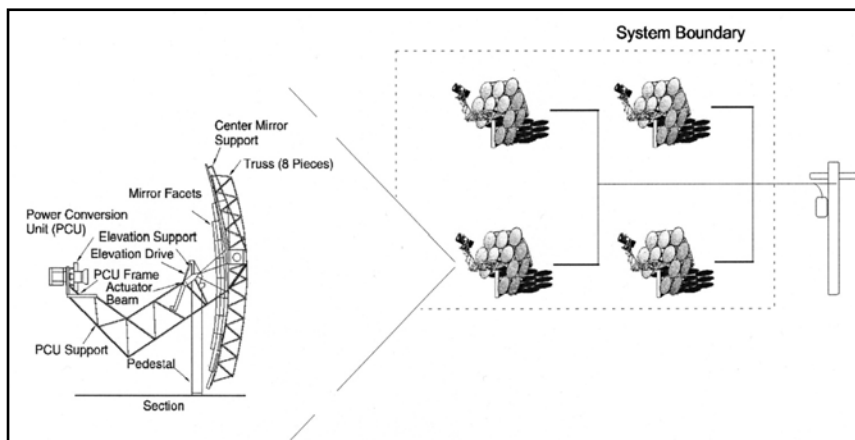
Concentrating Solar Power

Technology Description

Concentrating Solar Power (CSP) systems concentrate solar energy 50 to 5,000 times to produce high-temperature thermal energy, which is used to produce electricity for distributed- or bulk-generation power applications.

System Concepts

- In CSP systems, highly reflective sun-tracking mirrors produce temperatures of 400°C to 800°C in the working fluid of a receiver; this heat is used in conventional heat engines (steam or gas turbines or Stirling engines) to produce electricity at system solar-to-electric efficiencies of up to 30%. Systems using advanced photovoltaics (PV) cells may achieve efficiencies greater than 33%.



Representative Technologies

- A parabolic trough system focuses solar energy on a linear oil-filled receiver, which collects heat to generate steam and power a steam turbine. When the sun is not shining, steam can be generated with fossil fuel to meet utility needs. Plant sizes can range from 10 MWe to 100 MWe.
- A power tower system uses many large heliostats to focus the solar energy onto a tower-mounted central receiver filled with a molten-salt working fluid that produces steam. The hot salt can be stored efficiently to allow power production to match utility demand even when the sun is not shining. Plant size can range from 30 MWe to 200 MWe.
- A dish/engine system (see diagram above) uses a dish-shaped reflector to power a small Stirling or Brayton engine/generator or a high-concentrator PV module mounted at the focus of the dish. Dishes are 2 to 25 kW in size, can be used individually or in small groups, and are easily hybridized with fossil fuel.

Technology Applications

- Concentrating solar power systems can be sized for village power (10 kilowatts) or grid-connected applications (up to 100 megawatts). Some systems use thermal storage during cloudy periods or at night. Others can be combined with natural gas such that the resulting hybrid power plants can provide higher-value, dispatchable power.
- To date, the primary use of CSP systems has been for bulk power supply to the southwestern grid. However, these systems were installed under very attractive power purchase rates that are not generally available today. With one of the best direct normal insolation resources anywhere on Earth, the southwestern states are still positioned to reap large and, as yet, largely uncaptured economic benefits from this important natural resource. California, Nevada, Arizona, and New Mexico are each exploring policies that will nurture the development of their solar-based industries.

- In addition to the concentrating solar power projects under way in this country, a number of projects are being developed in India, Egypt, Morocco, and Mexico. In addition, independent power producers are in the early stages of design and development for potential parabolic trough and/or power tower projects in Greece (Crete) and Spain. Given successful deployment of systems in one or more of these initial markets, several domestic project opportunities are expected to follow.
- Distributed-systems deployment opportunities are emerging for dish-engine systems. Many states are adopting green power requirements in the form of “portfolio standards” and renewable energy mandates. While the potential markets in the United States are large, the size of developing worldwide markets is immense. The International Energy Agency (IEA) projects an increased demand for electrical power worldwide more than doubling installed capacity. More than half of this is in developing countries; and a large part is in areas with good solar resources, limited fossil fuel supplies, and no power distribution network. The potential payoff for dish/engine system developers is the opening of these immense global markets for the export of power generation systems.

Current Status

- CSP technology is generally still too expensive to compete in widespread domestic markets without significant subsidies. Consequently, RD&D goals are to reduce costs of CSP systems to 5¢/kWh to 8¢/kWh with moderate production levels within five years, and below 5¢/kWh at high production levels in the long term.
- Nine parabolic trough plants, with a total rated capacity of 354 MWe, were installed in California between 1985 and 1991. Their continuing operation has demonstrated their ability to achieve commercial costs of about 12¢/kWh to 14¢/kWh. O&M costs at these plants have declined by 40% due to technological improvements, saving the commercial plant operators \$50 million.
- Solar Two, a 10-MWe pilot power tower with three hours of storage, also installed in California, provided technical information needed to scale up to a 30-100 MW commercial plant, the first of which is now being planned in Spain.
- A number of prototype dish/Stirling systems are currently operating in Nevada, Arizona, Colorado, and Spain. High levels of performance have been established; durability remains to be proven, although some systems have operated for more than 10,000 hours.
- The CSP industry includes 25 companies who design, sell, own, and/or operate energy systems and power plants based on the concentration of solar energy. CSP companies include energy utilities, independent power producers or project developers, equipment manufacturers, specialized development firms, and consultants. While some firms only offer CSP products, many offer related energy products and services. Four of the 25 are “Fortune 500 Companies.” Current companies include:

Duke Solar Energy, LLC	Stirling Energy Systems
Nexant (a Bechtel Technology & Consulting Company)	Science Applications International Corp.
The Boeing Company	STM Corporation
KJC Operating Company	WGAssociates
SunRay Corporation	Morse & Associates
Arizona Public Service Corporation	United Innovations Inc.
Spencer Management Associates	Reflective Energies
Kearney & Associates	Industrial Solar Technologies
Nagel Pump	Spectralab
Clever Fellows Innovative Consortium	Salt River Project
Array Technologies	Energy Laboratories Inc.
Concentrating Technologies	Amonix
Ed Tek Inc.	

Technology History

Organized, large-scale development of solar collectors began in the United States in the mid-1970s under the Energy Research and Development Administration (ERDA) and continued with the establishment of the U.S. Department of Energy (DOE) in 1978.

Troughs:

- Parabolic trough collectors capable of generating temperatures greater than 500°C (932 F) were initially developed for industrial process heat (IPH) applications. Acurex, SunTec, and Solar Kinetics were the key parabolic trough manufacturers in the United States during this period.
- Parabolic trough development also was taking place in Europe and culminated with the construction of the IEA Small Solar Power Systems (SSPS) Project/Distributed Collector System in Tabernas, Spain, in 1981. This facility consisted of two parabolic trough solar fields – one using a single-axis tracking Acurex collector and one the double-axis tracking parabolic trough collectors developed by M.A.N. of Munich, Germany.
- In 1982, Luz International Limited (Luz) developed a parabolic trough collector for IPH applications that was based largely on the experience that had been gained by DOE/Sandia and the SSPS projects.
- Southern California Edison (SCE) signed a power purchase agreement with Luz for the Solar Electric Generating System (SEGS) I and II plants, which came online in 1985. Luz later signed a number of Standard Offer (SO) power purchase contracts under the Public Utility Regulatory Policies Act (PURPA), leading to the development of the SEGS III through SEGS IX projects. Initially, the plants were limited by PURPA to 30 MW in size; later this limit was raised to 80 MW. In 1991, Luz filed for bankruptcy when it was unable to secure construction financing for its 10th plant (SEGS X).
- The 354 MWe of SEGS trough systems are still being operated today. Experience gained through their operation will allow the next generation of trough technology to be installed and operated much more cost-effectively.

Power Towers:

- A number of experimental power tower systems and components have been field-tested around the world in the past 15 years, demonstrating the engineering feasibility and economic potential of the technology.
- Since the early 1980s, power towers have been fielded in Russia, Italy, Spain, Japan, and the United States.
- In early power towers, the thermal energy collected at the receiver was used to generate steam directly to drive a turbine generator.
- The U.S.-sponsored Solar Two was designed to demonstrate the dispatchability provided by molten-salt storage and to provide the experience necessary to lessen the perception of risk from these large systems.
- U.S. industry is currently pursuing a subsidized power tower project opportunity in Spain. This project, dubbed “Solar Tres,” represents a 4x scale-up of the Solar 2 design.

Dish/Engine Systems:

- Dish/engine technology is the oldest of the solar technologies, dating back to the 1800s when a number of companies demonstrated solar-powered steam Rankine and Stirling-based systems.
- Development of modern technology began in the late 1970s and early 1980s. This technology used directly illuminated, tubular solar receivers, a kinematic Stirling engine developed for automotive applications, and silver/glass mirror dishes. Systems, nominally rated at 25 kWe, achieved solar-to-electric conversion efficiencies of around 30 percent. Eight prototype systems were deployed and operated on a daily basis from 1986 through 1988.
- In the early 1990s, Cummins Engine Company attempted to commercialize dish/Stirling systems

based on free-piston Stirling engine technology. Efforts included a 5 to 10 kWe dish/Stirling system for remote power applications, and a 25 kWe dish/engine system for utility applications. However, largely because of a corporate decision to focus on its core diesel-engine business, Cummins canceled their solar development in 1996. Technical difficulties with Cummins' free-piston Stirling engines were never resolved.

- Current dish/engine efforts are being continued by three U.S. industry teams - Science Applications International Corp. (SAIC) teamed with STM Corp., Boeing with Stirling Energy Systems, and WG Associates with Sunfire Corporation. SAIC and Boeing together have five 25kW systems under test and evaluation at utility, industry, and university sites in Arizona, California, and Nevada. WGA has two 10kW systems under test in New Mexico, with a third off-grid system being developed in 2002 on an Indian reservation for water-pumping applications.

Technology Future

The levelized cost of electricity (in constant 1997\$/kWh) for the three CSP configurations are projected to be:

	<u>2000</u>	<u>2010</u>	<u>2020</u>
Trough	9.5	5.4	4.4
Power Tower	9.5	4.8	3.6
Dish/Engine	17.9	6.1	5.5

Source: *Renewable Energy Technology Characterizations*, EPRI TR-109496, 1997 for Dish/Engine, and Program values for Trough and Power Tower.

- RD&D efforts are targeted to improve performance and lifetime, reduce manufacturing costs with improved designs, provide advanced designs for long-term competitiveness, and address barriers to market entry.
- RD&D goals are to reduce the cost of CSP systems to 5 to 8¢/kWh within five years at moderate production levels. Long-run goals are to reduce costs below 4¢/kWh at high production levels.
- Improved manufacturing technologies are needed to reduce the cost of key components, especially for first-plant applications where economies of scale are not yet available.
- Demonstration of Stirling engine performance and reliability in the field are critical to the success of dish/engine systems.
- DOE expects Dish/Stirling systems to be available by 2005, after deployment and testing of 1 MW (40 systems) during the next two years.
- Key DOE program activities are targeted to support the next commercial opportunities for these technologies, demonstrate improved performance and reliability of components and systems, reduce energy costs, and develop advanced systems and applications.
- The successful conclusion of Solar Two sparked worldwide interest in power towers. As Solar Two completed operations, an international consortium led by U.S. industry including Bechtel and Boeing (with technical support from Sandia National Laboratories), formed to pursue power tower plants worldwide, especially in Spain (where special solar premiums make the technology cost-effective), but also in Egypt, Morocco, and Italy. Their first commercial power tower plant is planned to be four times the size of Solar Two (about 40 MW equivalent, utilizing storage to power a 15MW turbine up to 24 hours per day).
- The World Bank's Solar Initiative is pursuing CSP technologies for less-developed countries. The World Bank considers CSP as a primary candidate for Global Environment Facility funding, which could total \$1B to \$2B for projects during the next two years.

Source: National Renewable Energy Laboratory. *U.S. Climate Change Technology Program. Technology Options: For the Near and Long Term*. DOE/PI-0002. November 2003.

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Market Data

U.S. Installations (electric only)

Source: Renewable Energy Project Information System (REPiS), Version 7, NREL, 2003, and *Renewable Energy Technology Characterizations*, EPRI TR-109496.

Cumulative (MW)	1980	1985	1990	1995	1996	1997	1998	1999	2000	2001	2002
U.S.	0	24	274	354	364	364	364	364	354	354	354
Power Tower	0	10	0	0	10	10	10	10	0	0	0
Trough	0	14	274	354	354	354	354	354	354	354	354
Dish/Engine	0	0	0	0	0	0	0.125	0.125	0.125	0.125	0.125

Annual Generation from Cumulative
Installed Capacity (Billion kWh)

Source: EIA, Annual Energy Outlook 1998-2004 Table A17, Renewable Resources in the Electric Supply, 1993 Table 4.

	1980	1985	1990	1995	1996	1997	1998	1999	2000	2001	2002
U.S.			1*	0.82	0.90	0.89	0.89	0.87	0.49	0.54	0.54

* Includes both solar thermal and less than 0.02 billion kilowatthours grid-connected photovoltaic generation.

Annual U.S. Solar Thermal
Shipments (Thousand Square
Feet)

Source: EIA - *Annual Energy Review 2003* Table 10.3 and *Renewable Energy Annual 2003* Table 11.

	1980	1985	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003
Total 1	19,398	N/A	11,409	7,666	7,616	8,138	7,756	8,583	8,354	11,189	11,663	11,444
Imports	235	N/A	1,562	2,037	1,930	2,102	2,206	2,352	2,201	3,502	3,068	2,986
Exports	1,115	N/A	245	530	454	379	360	537	496	840	659	518

1 Total shipments as reported by respondents include all domestic and export shipments and may include imports that subsequently were shipped to domestic or to foreign customers.
No data are available for 1985.

Technology Performance

Efficiency		Source: <i>Renewable Energy Technology Characterizations</i> , EPRI TR-109496, 1997 (this document is currently being updated by DOE, and the values most likely will change), and TC revisions made by Hank Price of NREL for Trough technologies and Scott Jones of Sandia National Laboratory for Power Towers in 2001.							
		1980	1990	1995	2000	2005	2010	2015	2020
Capacity Factor (%)	Power Tower			20.0	43.0	44.0	65.0	71.0	77.0
	Trough			34.0	33.3	41.7	51.2	51.2	51.2
	Dish			12.4	50.0	50.0	50.0	50.0	50.0
Solar to Electric Eff. (%)	Power Tower			8.5	15.0	16.2	17.0	18.5	20.0
	Trough			10.7	13.1	13.9	14.8	14.8	15.6
	Dish/Engine								
Cost*		1980	1990	1995	2000	2005	2010	2015	2020
Total (\$/kWp)	Power Tower				1,747	1,294	965	918	871
	Trough			4,033	2,103	1,633	1,277	1,185	1,072
	Dish/Engine			12,576	5,191	2,831	1,365	1,281	1,197
Total (\$/kWnameplate)	Power Tower				3,145	2,329	2,605	2,475	2,345
	Trough			4,033	3,154	2,988	2,766	2,568	2,323
	Dish/Engine			12,576	5,691	3,231	1,690	1,579	1,467
O&M (\$/kWh)	Power Tower			0.171	0.018	0.006	0.005	0.004	0.004
	Trough			0.025	0.017	0.013	0.009	0.007	0.007
	Dish/Engine			0.210	0.037	0.023	0.011	0.011	0.011
Levelized Cost of Energy (\$/kWh)	Power Tower				0.101	0.066	0.051	0.044	0.038
	Trough			0.160	0.101	0.077	0.057	0.052	0.047
	Dish/Engine				0.179		0.061	0.058	0.055

* Cost data for trough and power tower technologies are from 2001 revisions (in 2001\$). Dish/Engine data for \$/kWp excludes costs of hybrid system and \$/kWnameplate includes hybrid costs (in 1997\$).